Collecting knowledge of biking behavior in Copenhagen using GPS

The GPS data collection

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BIKE ABILITY

Collecting knowledge of biking behavior in Copenhagen using GPS

– The GPS data collection

contents

1: about the project

This project aimed to create knowledge about cyclists' behavior and movement patterns in the city of Copenhagen based on a GPS survey using GPS data from the involved cyclists, hereafter called respondents. The GPS tracking method were used as a tool to get information about the respondents' biking behaviors.
The whole bikeability research project is a joint venture between Aalborg University and the University of Copenhagen, and the following report presents a brief description of how the GPS survey was carried out and the report serves as documentation for the data collection process and the quality of the GPS data collected. The data will be used in a model developed by Hans Skov Petersen from the research group Life, at the University of Copenhagen in autumn 2011.
Basically, the aim of the GPS survey was to ask 200 respondents to carry a GPS receiver for one week i.e. seven days, tracking them every time they used a bike – this included among others thing when going to and from work, going shopping, visiting friends, picking up children from school, and exercising - all the tasks a bike is used for in daily life. The collection of data carried out from 1st of April to 15th of June 2011.
Together with the Life research group it was decided to use information from 200 respondents in total. The survey was divided into three sections (3 x 70 respondents, i.e. 210 respondents in total) – each section following the same procedure, covering three weeks in total:

- One week to prepare and charge 70 GPS receivers
- One week of data collection where the GPS receivers were in the hands of the respondents
- One week to collect the GPS receivers from the respondents

Figure 01 shows the timeline for the survey and the different tasks that were carried out in the different phases of the survey.
210 GPS receivers were handed out in total. After all three rounds had been completed a total of 200 people had participated in the survey. Ten respondents ended up not participating in the survey at all for various reasons; these will be discussed later in the report. Among the participating respondents 65 % carried their GPS receiver for the whole week, 16 % carried their GPS receiver for 6 days, 13% carried their GPS receiver for 4-5 days, 4% carried for 2-3 days and only 2% carried it for one day only.

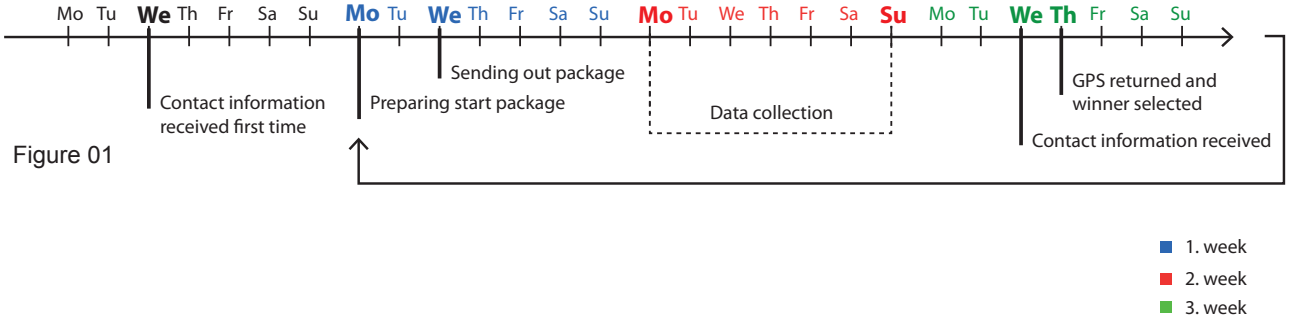


Figure 01


la.com

2: preparing the technical setup

The practical execution of a survey based on GPS receivers demands a great deal of preparation of the units before the actual data collection can begin. The preparations are mainly technical; such as updating software and checking and assigning ID numbers, checking the batteries of the units, and the setting up of the database. The preparations will be described below.

2.1: ID NUMBER

All the GPS units contained an ID number from the software dealer Care4All. When given to the AAU research group an AAU ID number was added to each of them as well. Before starting the Bikeability project the AAU research group had 40 GPS receivers, all with an AAU ID number. For the Bikeability project another 30 GPS units were bought to ensure a total capacity of 70 GPS receivers. All the new GPS receivers were given an AAU ID number in line with the already existing AAU ID numbers of the 40 existing GPS units.

The ID number serves two functions: First, it is the only way the AAU research group can distinguish the GPS information once it is stored in the database. This means that the following analysis of the data, after the data collection had finished, is based on the GPS receiver ID numbers registered in the database. Second, it is the only way data from a GPS unit can be associated with a respondent during the data collection. Before sending out the GPS receivers the research group assigned each respondent with a personal GPS receiver ID number, to create an overview of who has which GPS unit during the data collection. This is needed especially in case of problems during the data collection. While in the hands of the respondents problems with the GPS unit may occur. The problems can vary from the respondent not being able to turn on the GPS receiver to the GPS receiver malfunctioning; problems like this cannot be prevented beforehand by the research group but can, nevertheless, be anticipated.

2.2: BATTERIES

The calculation of the position can be divided into three steps:

1) The position is calculated through contact with the satellites;
2) The position is sent to the database via GSM;
3) A few seconds where nothing happens, then the cycle restarts, this is also known as the logging frequency

The last variable, the logging frequency, was expected to have an impact on the GPS receiver's battery life. As it was the aim to make the batteries of the GPS receivers last for as many hours as possible in order to make the collection of data less inconvenient for the respondents, thus two tests were carried out to figure out how much the logging frequency influenced the GPS receiver's battery life.

The first test, a pilot survey, was carried out with three GPS units; the longevity of the batteries was tested when the logging frequency was set to 10 second. For one week three test persons carried a GPS receiver when biking to and from work. The pilot survey showed that with a logging frequency of 10 seconds, the longevity of the batteries was on average seven hours.

Important information came out of this pilot survey. The data showed that if the GPS unit was carried in an inner pocket or at the bottom of a bag, the GPS receiver struggles at reading the satellite signal properly. Consequently, is was highlighted in the contact with the respondents that the GPS receiver should always be carried in a way that would ensure that satellite signals can be read i.e. the GPS receiver had to be carried in a thin jacket pocket or in other ways be somehow visible (See chapter 3.2; the welcome letter for more details).

In the second test the logging frequency of the GPS units was changed. Instead of sending geo-positioning data every 10 seconds, it was changed to every 15 seconds. To test if this change had any impact on the battery life 10 GPS receivers were carried around Aalborg for one day. The test was carried out in collaboration with NT (Nordjyllands Trafikselskab); one of the company's busses drove around with all 10 GPS units for one day. Beforehand all 10 GPS receivers were set to charge overnight so all the batteries were fully charged. Among the 10 GPS units five were set to a logging frequency of 10 seconds, five with a logging frequency of 15 seconds.

Figure 02 illustrates how six out of the 10 GPS receivers ran out of battery. Graph one shows the battery life of the GPS receivers in minutes, graph two shows how many points (geo-positions) each of the six GPS units sent to the database, while the last graph shows how many points each GPS receiver sent in total all the time they were turned on. For all three graphs the mean is calculated.

As all three graphs illustrate in their own way, there is no particular difference between the two logging settings. The GPS units with ID 211, 212 and 213 show when the batteries ran out of battery when the unit is configured with a logging frequency of 10 seconds. The GPS units with ID 223, 225 and 229 show when the batteries ran out when the unit is setup with a logging frequency set to

15 seconds. After an average of seven hours the battery ran out in both setups. The graphs also show that all of the GPS receivers sent more or less the same amount of information to the database. The GPS receivers with 10 seconds logging send around 2000 points in total whereas the GPS units with a logging frequency of 15 seconds send around 1600 points. All of the GPS receivers send an average of 2.5 points per minute: regardless of whether the GPS units had a 10 or 15 seconds logging frequency.
The battery tests show another important fact about the GPS receivers. Within the first seven hours the frequency is regular and the unit logs every 10 or 15 second depending on the settings. After seven hours the frequency becomes unstable. This means that even if the receiver is still turned on for another couple of hours, the frequency for calculating the geo-positioning becomes irregular. Thus the respondents were encouraged to charge their GPS unit every seven or eight hours.
The logging frequency influences how often data about the geo-position is sent to the database. The slower the frequency the more distance there will be between the geo-positions. As the tests showed that there were no major differences in the battery life whether the logging frequency was 10 or 15 seconds, a login frequency of 10 seconds was chosen, as this would contribute more geo-positions to the dataset.

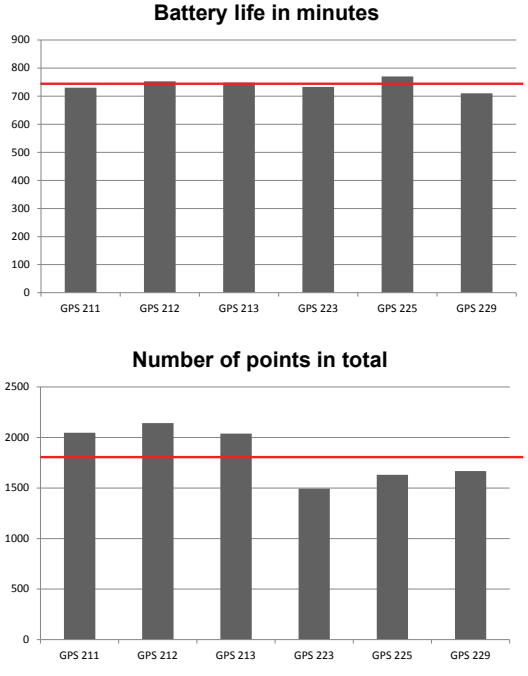


Figure 02

The value of the above mentioned assumptions can be criticized as it is based on a poor statistical background; though it seems possible to reach to the conclusion that changing the logging frequency does not noticeably extend the battery life of the GPS receivers.

2.3 Setup for the Database and Web Interface

The database is where all the information from the GPS receivers is stored. As this data is the raw material containing all the information each GPS unit sends every 10 seconds, the data needs to be cleansed and thoroughly filtered before it is useable for GIS analysis. This process will be described further in chapter 6.
To have a more accessible version of the database during the data collection; a web interface where the activity from each GPS receiver could be monitored was configured. The web interface created a quick overview of the data coming in. In the web interface the ID numbers of the GPS receivers were shown. Furthermore the web interface contained information about last update, last position, battery level, latest routes on Google map and no/off status.
In addition, another feature was added to the interface, as it was programmed to notify the user when a GPS receiver had been turned off for more than 24 hours and/or if the battery level was low. This was done through color changes. When the battery level was getting low the GPS receiver's indicator would turned yellow. If the GPS receiver had been turned off for 24 hours or more the indicator would turn red. With the web interface a simple setup was established to ensure that the GPS receivers were operational when handed out to the respondents.
Having a GPS receiver turned off for a longer period of time equals loss of data, which therefore made it imperative that the respondents were informed as soon as their GPS unit needed to be charged.
Only the AAU research group had access to the web interface.

3: preparation of the practical setup

There are two main considerations that have to be taken into account when using GPS equipment to survey biking behaviour. One is the preparation of the technical setup as described above. The other consideration is how to best notify the respondents of the necessary information at the right time; in order to secure the quality of GPS receivers' data tracking. From this perspective the right information includes how to use the GPS receivers, and information about the overall survey process; i.e. when and what to do at the exact time.
It was expected that not all the respondents would be familiar with GPS technology, thus a lot of effort was put into giving the respondents information about GPS technology that would make them comfortable with using it. Furthermore, a lot of information had to be sent to the respondents during their participation in the survey to inform them about important dates regarding the start-up and the end of the survey. Different means of communication were used to send the information to the respondents. The aim of this chapter is to describe how the involvement of the respondents was prepared and later on implemented.

3.1 CONTACT WITH THE RESPONDENTS

It was necessary for the AAU research group to have contact with the respondents before, during, and after the data collection to provide them with important information about and help with the GPS units. Contact information for the respondents was therefore required, as it was also needed to send out the GPS receivers at the beginning of the survey.
This contact information was provided by Hans Skov Petersen from the University of Copenhagen and was received by the team at AAU one week before the GPS receivers were handed out to the respondents. This margin was necessary to prepare the GPS receivers and validate the addresses and mobile numbers of the respondents. The information about the respondents provided by Hans Skov Petersen contained categories such as; name, respondent ID number, address, zip code, city, phone number and e-mail address. All of this was essential information for the contact with the respondents during the survey.
The respondent ID number (given by the University of Copenhagen) was linked to the AAU ID for the GPS receiver, which in both cases is unique and thereby ensures a 100% reliable link between the respondents and the GPS units. The address and mobile number were used to validate that it was the right respondent who received the GPS unit. Before accepting to participate in the GPS survey the respondents had filled out a questionnaire where they had accepted participating in the GPS survey as well. In cases where there had been giving misleading or wrong addresses the GPS receivers were sent back to the research group. This happened four times during the survey.

3.2: THE START PACKAGE

A start package was sent out the Wednesday before they survey from the office at the University of Copenhagen to make sure that the GPS receivers were received by the respondents before the start of the survey. By sending it out on Wednesday the respondents received it three to four days before the GPS data collection was to start. The package consisted of six things:

- A welcome letter
- A manual on how to use the GPS receiver
- A GPS receiver
- A charger
- A carrier strap for the GPS unit
- A pre-stamped envelope with the address of the University of Copenhagen

The Welcome Letter
The welcome letter offered an introduction to the survey and explained and contained all the information necessary to participate. The letter included information about:

- Where, how and for how long they should carry the GPS receiver. The letter emphasized the start and end dates of the survey
- The text messages (SMS) that would be sent out to them during the survey
- Where to carry the GPS unit when biking. The GPS receiver had to be carried in a thin pocket or somehow visible, to ensure reception of high strength signals from the satellites. If carried at the bottom of a bag the data would be inconsis tent
- How to return the GPS unit when the survey had finished. The GPS receivers should be re turned in the pre-stamped envelopes
- The rules for participating in the lottery (see chapter 3.4 for a further description of the lottery). For participating in the survey each respondent had the opportunity to win one of two bicycle helmets with a value of 1000 DKK.

The welcome letter is shown in figure 03.
The address of each respondent was included in the

Kære Trine Jensen

Tak fordi du vil deltage i undersøgelsen af cykelisters adfærd i byen. Formålet med undersøgelsen er at forbedre vilkårene for cyklister. Til det skal vi bruge din hjælp til at vise os, hvordan og hvor du cykler i byen. Du vil være 100 % anonym i undersøgelsen, og al data behandles fortroligt. Du kan læse mere på www.bikeability.dk lavet i samarbejde med Københavns Universitet og Aalborg Universitet.

Alt du behøver for at deltage, er at have en GPS på dig i en uge, når du cykler. Det gælder, både når du bevæger dig til og fra arbejde, til indkøb, når du skal besøge venner og familie, eller hvad du ellers måtte foretage dig i løbet af ugen. Der er intet krav til, hvor meget eller lidt man skal cykle for at være med i undersøgelsen.

Undersøgelsen starter mandag den 23. maj, og varer til søndag den 29. maj. I den tilsendte pakke ligger der en GPS, som du bedes have på dig i denne uge.

GPS'en er nem at betjene, og kræver regelmæssig opladning på samme måde som en mobiltelefon. **Første gang** du sætter GPS'en til opladning, skal du tænde for den, ved at trykke på den store røde knap. Se vedlagte brugsvejledning. Du ved at GPS'en er tændt, når alle indikationslamperne blinker med jævne mellemrum. Hvis GPS'en efterfølgende løber tør for strøm, tændes den automatisk igen, når den sættes til opladning. Det er derfor **IKKE** nødvendigt at trykke på tænd/sluk knappen senere hen i undersøgelsen.

Husk at tjekke om GPS'en er opladet, inden du tager den med om morgenen.

Vi sender dig en sms dagen før undersøgelsen starter, hvor vi minder dig om, at du skal lægge din GPS til opladning. Vi sender dig yderligere en sms på dagen, når undersøgelsen starter, for at huske dig på, at du skal medbringe din GPS. Du vil blive kontaktet, hvis din GPS er slukket i mere end et døgn. GPS'en skal bæres synligt eller placeres i en yderlig lomme, da det ellers ikke er muligt for GPS'en at komme i kontakt med satellitterne.

Når undersøgelsen er slut, bedes du sende GPS, oplader og rem tilbage i vedlagte svarkuvert. Portoen er betalt. Torsdag den 2. juni trækker vi lod, blandt de 70 deltagere i undersøgelsen, der har sendt GPS'en retur, om to cykelhjelme á 1000 kr. til Fricykler. Cykelhjelmen kan altid byttes til noget andet i butikken. Det er vigtigt, at du sender GPS'en til os inden lodtræningen, for at kunne være med. Vinderne får direkte besked.

Har du nogle spørgsmål, er du velkommen til at kontakte Niels Thuesen på telefonnummer: 30 71 47 20. Du kan også skrive en mail til: nthu@create.aau.dk. Har du spørgsmål undervejs til GPS'en, er du selvfølgelig også velkommen til at kontakte os.

Med venlig hilsen

Niels Thuesen
Videnskabelig assistent
Aalborg Universitet

Figure 03

welcome letter with the help of the mail merge function in Windows office. The letters were merged with the respondents' addresses. In this way, the addresses of the respondents were automatically added when preparing the welcome letters.
After the first round of data collection the instruction in the letter were changed, so that it was stated that the respondents should only carry the GPS receiver when biking. Many respondents from the first round got confused after receiving the letter, as the information was somehow misleading. The content in the letter made some of the respondents think that they should carry the GPS unit on them all day no matter which kind of transport they were using, i.e. by car, walking, or by public transport. This was of course never the case, which made the AAU research group emphasize in the following two letters that the GPS units should only be carried when the respondents were biking.
In cases of a combination of different modes of transportation it was accepted that the GPS receiver would be turned on during the whole journey. A situation like this could be a respondent using the bike to get to the train station and then take a train to go to work. It will show in the data if other modes of transport have been used in combination with a bike.
In the letter it was also emphasized that both the charger and the strap should be returned.

The Manual
The manual for using the GPS unit was made by the research group at Aalborg University. To make the manual as simple as possible it was decided to only give information about how to turn the GPS receiver on and off, as well as how to charge it.
As all GPS receivers are equipped with three small lights indicating different technical setups, the manual furthermore explained the functioning of these lights on the GPS unit. By describing the function of the different lights the respondents could check if the GPS receiver was turned on or off, if the GPS receiver was able to read satellite signals and also if it had contact to the server. The manual can be seen in figure 04
The blue light indicates whether or not satellite signals are available. The light emits one longer flash followed by some quicker flashes. The number of the quick flashes indicates the number of visible satellites.
The green light indicates whether the GPS unit is turned on.
The yellow light indicates if there is a connection to the GSM network. This is required to send the data from the GPS receiver to the database.

The GPS receiver
It was arranged by the AAU research group that all GPS units were completely out of battery when send out to the respondents. In this condition the GPS receiver will automatically start when put in the charger. To send the GPS unit out in this condition would therefore prevent the respondents from worrying about whether the GPS receiver was turned on or not. As soon as it was put into the charger, it would start by itself. In order to instruct the respondents, text messages were sent to them.
The first text message was sent out Sunday evening (the day before the survey started) telling the respondents to charge their GPS unit over night before the survey started Monday morning, this was meant to ensure that all GPS receivers were fully charged and turned on the first day of the survey. Despite the SMS some of the respondents still did not charge their GPS units, which resulted in no data transmitted from the GPS receivers on Monday morning.
It takes an average of six hours to fully charge the batteries of the GPS receivers. To charge the GPS receiver over night was therefore expected to be a sufficient amount of time to charge it.

The Charger
The charger is a 230V USB charger and comes with the GPS equipment. The charger can be plugged in all Danish standard wall plugs.

The GPS Strap
The GPS receiver strap was sent with the GPS receiver in order to make it easier for the respondents to carry the GPS around. It was up to the respondents to decide whether to use it or not. It was simply removed from the GPS unit if preferred by the respondents. The strap had the logo of Aalborg University.

The Pre-stamped Envelope
The welcome package contained an unused envelope with the address for the office at the University of Copenhagen. This envelope was for the respondents to return the GPS receiver, the charger and the strap. The envelope was stamped beforehand to avoid any cost for the respondents.

BRUGSVEJLEDNING

Tænd/Sluk

Første gang du sætter din GPS til opladning, skal du tænde for den ved at trykke på den store røde knap midt på GPS'en. Når alle indikationslamperne lyser, er din GPS tændt. Hvis din GPS senere hen løber tør for strøm og slukkes, vil den efterfølgende tændes automatisk, når den sættes til opladning. Det vil derfor IKKE være nødvendigt at tænde for den igen på tænd/sluk knappen. Når GPS'en sættes til opladning, lyder meddelelsen: 'Charging charging'. Det betyder, at din GPS er ved at lade op.

Tænd/sluk knap

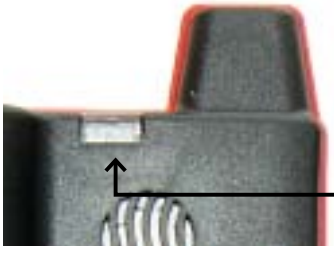
Opladening

GPS'ens batteri har en begrænset levetid. Din GPS skal derfor oplades i løbet af dagen. Det er vigtigt, at du har opladeren med dig, hvis du er længere tid hjemmefra, enten på arbejde, i skole, besøger venner osv. Det er en god idé at sætte din GPS til opladning, hver gang du er i nærheden af en stikkontakt, og sæt den altid til opladning natten over. Hvis din GPS er ved at løbe tør for strøm, vil du modtage en besked på din mobiltelefon herom. Når GPS'en er fuldt opladet, lyder meddelelsen: 'charging completed'. Når du fjerner GPS'en fra opladeren, er GPS'en automatisk tændt. Du skal derfor IKKE tænde den, når du tager den ud af opladeren.

Til opladning

Lamper

Tre forskellige lamper blinker med jævne mellemrum. Lamperne indikerer: Grøn = tændt, Gul = Kontakt til server, Blå = Forbindelse til satellit. Du skal holde øje med, at alle tre lamper blinker, da det indikerer, om din GPS er tændt, og om der er forbindelse til satellitten. Antallet af blå blink viser hvor mange satellitter, der er forbindelse til. 3 hurtige blink betyder således, at der er forbindelse til 3 satellitter. Der skal helst være 3-4 hurtige blink i træk.



Indikations lamper

Figure 04

3.3 TEXT MESSAGES

Beside the start package sent out four to five days before the data collection started, the main part of the communication from the research group to the respondents was via text messages. The text messages that were sent out contained information about when the survey started and ended and also about the status of the energy level of the batteries.

Linkpoint Text Messages
To maintain connection with the respondents during the data collection, a collective text sending database was established on the website www.linkpoint.com. From this database it was possible to send out messages to all of the respondents simultaneously. The database automatically generated the messages by combining the respondent data with the pre-made text messages formulated by the research group. The joining of data made it possible to personalize each text message so all the respondents were addressed with their name.
In total four different texts were sent out to all of the respondents in the course of the data collection.

Text 1: Sunday at 6 pm the first text is sent out to notify the respondents to remember to charge the GPS receiver before the survey starts the following day, i.e. Monday.

Text2: Monday at 8 am a text message was sent out to remind the respondents to bring the GPS unit along with them when going to work or school. The text was also to remind them that the GPS receiver should be carried visibly or in a thin jacket pocket so the signal from the satellites was not obstructed.

Text3: The following Sunday (one week after Text1) the third text message was sent out to remind the respondents that the survey was over. In the text messages a 'thank you' for their participation in the survey was included.

Text4: The final text was sent out Monday morning (one week after Text2) at 8 am. This text message reminded the respondents to send the GPS back in the pre-stamped envelope, received with the start package. This extra text was sent out because previous tests showed that getting the GPS receiver back can be difficult and because of the short time between the survey rounds which made it important to get the GPS receivers as soon as possible, in order to be able to send them out to the next respondents.

After the first round the research group found it necessary to adjust the message in Text4. When the respondents returned the GPS unit, then the charger or the strap or both were often missing. It was therefore decided to incorporate a reminder to return all three parts and not just the GPS receiver.
Appendix A shows all four text messages that was sent out (In Danish)

Database Text Messages
A text message was sent to the respondents if the battery for the GPS unit was running low. This was created to ensure that the respondents paid attention to the battery level of their GPS receiver. By linking the AAU ID and the respondent's ID number with the respondent's phone number the database was configured to send out a text message to the respondent's mobile phone when the power level was down to 1/3. This meant that the respondents received a text messages that notified them, every time the GPS receiver needed to be charged.
The text messages generated in the database were formulated as follows:

1090204034 17-05-2011 10:56:11 batterispænding er lav
(Serial number of the GPS – the date – the time – the message)

During the three rounds a total of 357 text messages were sent to the GPSs that was running out of battery

3.4 A LOTTERY

To encourage the respondents to participate in the survey a lottery was established. To participate in the lottery it was necessary to return the GPS receiver within two days after the survey had ended; this information was also included in the welcome letter. The lottery had two objectives.

First, it was regarded as a reward for the respondents for their participation in the survey. Second, it was expected that a lottery would encourage the respondents to return the GPS receiver right after the survey had finished. In that way the research group would avoid that some of the GPS units were never returned or were returned late. Bike helmets were chosen as the prize the respondents could win. In total six respondents were picked as winners; two respondents from each round. The helmets each had a value of 1000 DKK.

4: collection of data

The collection of data was defined as those days where the GPS receivers were in the hands of the respondents, and the server received data about their biking behavior. For all three rounds the collection of data started on a Monday and lasted until the following Sunday. During these days the respondents were expected to carry their GPS units when biking. The following is a description of what kind of tasks that were carried out by the AAU research group during the data collection. The main task was to check if all the GPS units were working, to inform the respondents about the survey and to help the respondents in any way they needed in relation to the survey.

4.1 REGISTRATION OF GPS ACTIVITY

Every day the activity of the GPS units were checked in the database to make sure that the respondents had turned on their GPS receivers and that the battery level of the GPS receivers was not too low. The webpages showing the data was organized so if the GPS units were low on battery it was indicated by a yellow color and if the GPS receivers had not been turned on for 24 hours it was indicated by a red color. This gave the research group a quick and easy overview of the GPS units' activity.
Twice a day during the data collection the database was checked, first between 8-10 am and again from 4-6 pm. If a GPS receiver was turned off for 24 hours (the red colored lines) a text message was sent to the respondent to ask him or her to turn on the GPS unit and remember to carry it when biking. If the following day the GPS receiver was still switched off, the respondent was contacted by phone and asked why he or she had not turned on the GPS unit. This was done to determine whether the respondent still wanted to participate in the survey or not. After being contacted by phone, all of the respondents participated in the remaining days of the survey or had legitimate practical reasons for not participating.
Figure 05 shows an example of a database overview that illustrates which ones of the GPS units that needs to be charged. The yellow lines show which GPSs that need to be charged and who has been sent a text message, while the red lines illustrate which of the GPSs that have been turned off for 24 hours or more.
Special attention was paid to the activity of the GPS units the first day of the survey (Monday morning) to make sure that the GPS receivers were turned on. If the GPS units were switched off by 9 am a text was sent to the respondent as a reminder to turn on the GPS receiver and bring the GPS unit when going biking. If there on Tuesday was still no contact to the respondent the GPS receiver was declared "dead" and the procedure to get the GPS unit back started.

4.2 CONTACT TO RESPONDENT DURING DATA COLLECTION

The contact to the respondents was in this phase two-sided. In cases where a GPS receiver was not in use the research group had to contact the respondent, and when the respondent needed information about the functioning of the GPS receiver he or she had to contact the research group.
If there were any irregularities in the data collection the research group would contact the respondents mainly by phone, but in some cases also by email. All the contact between the University and respondents was recorded in a respond-log (see appendix Xx) where notes were added. These notes include information about whether the GPS receiver had been turn off or if the respondent for some reason could not participate for one or more day of the survey.
During the data collection phase, many respondents contacted the research group by phone or mail with questions regarding the use of the GPS receiver and the purpose of the survey. The last day of the data collection week (Sunday at 6 pm) Text3 was sent out to all of the respondents to remind them that the survey had finished. They were asked to send the GPSs back in the pre-stamped envelope the following day.

4.3 RETRIEVAL OF GPS RECEIVERS

The first day after the data collection had finished Text4 was sent to all of the respondents with a reminder to return the GPS unit. In this way as many as possible of the GPS receivers were returned the first day after the data collection had finished. However, it should be noted, that it has not been possible to evaluate whether the text message had an influence on this or if the respondent would have returned the GPS unit without the text message.
Almost 80% of the GPS receivers were returned with the envelope either Wednesday or Thursday. It is expected that these GPS units were sent by the respondents on Monday – the day they received Text4. On Thursday it was checked which of the GPS receivers that were still missing. In each round 10 to 12 respondents did not return their GPS receivers Monday or Tuesday. Some of these missing GPS units arrived after a phone call from the research group where the respondents were kindly asked to return the equipment.
Only a few GPS receivers were not returned after the phone calls. The reasons for this varied from the respon-

dent not having time to return it, or that the pre-stamped envelope had gotten lost. In these cases the GPS unit was picked up personally by a member of the research group at the respondent's home address. In all these cases the GPS receiver was handed over immediately.

4.4 CHECK OF THE GPS RECEIVERS

When all of the GPS units had been returned they were checked by the research group to validate that they were still working correctly. First, the GPS receiver's ability to read satellite signals was checked. Second, the battery function was checked.
In all three rounds two or three GPS units were damaged in the mail. These GPS receivers were sent back to the hardware dealer Care4All for repair. Care4All could in all cases repair the GPS receivers in one day, so the GPS receivers could be returned to the research group in time to be sent out again in the next round of the survey.
Furthermore, when the GPS units had been returned it was checked if the strap and the charger had also been returned along with the GPS receiver. In the first round many of the straps were not returned. Thus it was decided to emphasize in the welcome letter and the text messages in the following rounds that the strap should also be returned along with both the GPS unit and the charger. Despite this some chargers and straps were still not returned to the research group together with the GPS receiver. The missing chargers and straps were not collected afterwards.

4.5 WINNERS OF THE LOTTERY

On Thursday two winners of the lottery were chosen, and then contacted by email. The winners were randomly picked among the respondents who had been active during the data collection and from whom the GPS receiver had been returned on time.
The helmets were sent to the winners by post.

4.6 UNSUBSCRIBING THE TEXT MESSAGES

Immediately after the GPS units were returned to the AAU research group, the text message function in the GPS receiver was deactivated. The deactivation was necessary to avoid that the respondents would continue to get text messages regarding low battery levels after they had returned the GPS receivers to the research group. The text message function was activated again on the first day of the survey in the following round.

Statistics for lommies created at 2011-07-18 12:27:33

#	NodeId	Last updated	Last position	Battery level	# of positions	Diff from now, sec	See trail in Google Maps	Notes
1	2070123041	2011-06-20 06:56:21	55.7023717, 12.5535900	4064	42677	2439072	View in GoogleMap	
2	2070227032	2011-06-18 08:50:13	55.6913167, 12.5458417	3670	53150	2605040	View in GoogleMap	
3	2070227042	2011-05-30 05:36:13	55.6716783, 12.5344467	3877	17238	4258280	View in GoogleMap	
4	2070227056	2011-06-20 13:47:05	55.6975517, 12.5375350	3529	42090	2414428	View in GoogleMap	
5	2070302032	2011-06-20 14:59:49	55.6762200, 12.5609000	3522	17219	2410064	View in GoogleMap	
6	2070302033	2011-06-20 12:36:21	55.6932717, 12.5324500	3574	31148	2418672	View in GoogleMap	
8	1070919004	2011-06-20 09:26:36	55.6817517, 12.5199233	3554	64095	2430057	View in GoogleMap	
9	2070305026	2011-06-19 20:11:26	55.9996067, 12.0116817	3645	44626	2477767	View in GoogleMap	
10	2070306032	2011-06-20 08:28:21	55.7052100, 12.5350600	3554	34118	2433552	View in GoogleMap	
11	2070305057	2011-06-20 02:27:46	55.6977600, 12.5819817	3741	45979	2455187	View in GoogleMap	
12	2070305087	2011-06-19 23:31:30	55.6881033, 12.5439967	3516	74484	2465763	View in GoogleMap	
13	2070306023	2011-06-13 20:21:03	55.8321250, 12.2384067	3754	56098	2995590	View in GoogleMap	
14	2070306025	2011-06-18 01:10:25	55.6868000, 12.5495183	3645	63573	2632628	View in GoogleMap	
15	2070306026	2011-06-18 17:06:53	58.1409200, 9.3223600	3632	39693	2575240	View in GoogleMap	
16	2070306027	2011-06-20 16:32:58	55.6037750, 10.8216450	3677	54328	2404475	View in GoogleMap	
18	2070306029	2011-06-20 10:53:20	55.7225417, 12.5292633	3516	65680	2424853	View in GoogleMap	
19	2070306030	2011-06-15 03:08:30	55.6937867, 12.5431983	3600	45083	2884743	View in GoogleMap	
20	2070306031	2011-06-18 00:34:38	55.2254133, 11.7591633	3548	54856	2634775	View in GoogleMap	
21	2070305045	2011-06-20 23:53:34	55.6702700, 12.5691083	3593	63198	2378039	View in GoogleMap	
22	1070919016	2011-06-16 09:13:43	55.6698217, 12.5560683	3600	44605	2776430	View in GoogleMap	
23	2070306035	2011-06-15 02:52:23	55.6992767, 12.4972167	3645	21384	2885710	View in GoogleMap	
24	2070306038	2011-05-15 12:43:01	0.0000000, 0.0000000	4161	10981	5528672	View in GoogleMap	
25	1070919020	2011-06-08 09:07:02	0.0000000, 0.0000000	4206	15038	3468031	View in GoogleMap	
26	2070306040	2011-06-08 09:06:32	0.0000000, 0.0000000	4141	28805	3468061	View in GoogleMap	
27	2070306043	2011-06-19 09:24:15	55.6188650, 12.5841933	3625	77851	2516598	View in GoogleMap	

Figure 05

5: variations in the three setups

The preparation process and data collection were similar in all the three rounds with only minor differences. An example is the changes in the welcome letter and in the text messages regarding where and when to bring the GPS units during the week.

The numbers of active respondents in the first and the second round were more or less the same with 67 and 68 participating for the whole week among the originally 70 respondents the GPS receivers were sent to. In the third round the number of active respondents participating was a little lower with only 65. The reasons for the respondents to not participate despite their initial interest varied, but mostly it was caused by holiday or work overload.

Despite this high number of respondents, many of the respondents did not turn on their GPS receiver for one or more days during the seven days they were supposed to carry it when biking. 65% had the GPS unit turned on the whole week which is equivalent to 136 respondents.

In the third round, Monday the 13th of June 2011 was Pentecost which is a public holiday in Denmark. This day 27 of the respondents did not turn on their GPS receiver even though the survey was supposed to start that day, despite the fact the day was a holiday. However, almost all of the GPS receivers were turned on as expected the following Tuesday.

6: cleansing of the data

Cleansing of the data is necessary to extract meaning from the data collected during the survey's three rounds, as errors are unavoidable. This chapter accounts for the procedures which are used to clean up the dataset and remove as many outliers as possible, while losing as few valid loggings as possible. All filters involved in the data cleansing process revolve around the attributes recorded by the GPS-receivers. The attribute values are either used to filter loggings based on logics or theory or used in more complex algorithms, which are related to the discipline of Spatial Data Mining. The last-mentioned includes Peter Bro and Anders Sorgenfri Jensen's algorithm for recognition of trips and stays [http://vbn.aau.dk/da/publications/distinguishing-movement-from-stays-during-continual-gps-tracking(77ecaac0-e402-11de-abf1-000ea68e967b).html] as well as an algorithm for identifying a very specific error which occasionally happens during the positioning phase – an error which is dubbed the Linear Path Scattering in this paper. The two algorithms are executed before the simpler attribute-based filtering steps, as the algorithms need erroneous data to recognize patterns.

The procedure for the data cleansing process can be seen in Table 01

The effect of each filter is illustrated on two scales – on the national level and on the case area. The delimitation of the case area can be seen in Figure 06.

Due to the fact that a single logging can be affected by multiple errors, each of the visualizations illustrates the individual effect of a filter. That is, the maps illustrate the amount of data removed from the original raw dataset, and not the accumulated number of removed loggings based on using the current filter in conjunction with previously described filters.

Figure 06

Step	Filter
0	None (the raw data)
1	Division into trips and stays
2	Linear Path Scattering
3	Geographic delimitation of the case area
4	Insufficient amount of visible satellites
5	Excessive velocity
6	The parameter Time To Fix
7	All erroneous loggings

Table 01

6.1 STARTING POINT - THE RAW DATA

The basis of the data cleansing is a dataset consisting of 2,753,401 loggings. This is the total amount of data gathered throughout the three weeks. A visualization of the raw data can be seen in Figure 07.

6.2 DIVISION INTO TRIPS AND STAYS

The first filter appends an attribute which indicates whether a logging is recorded during movement or when the receiver's location is fixed. The mechanism behind the filter is an estimate of whether the logging has the highest probability of having been recorded during a trip or during a stay. The estimate is based on the logging's relationship with neighboring loggings which are closely related in space and time. Empiric studies indicate that the algorithm estimates correctly in approximately 92 % of the cases. The amount of loggings recorded during trips and stays respectively can be seen in Table 02.

Loggings recorded during trips	Loggings recorded during stays
1,051,390	1,702,011

Table 02

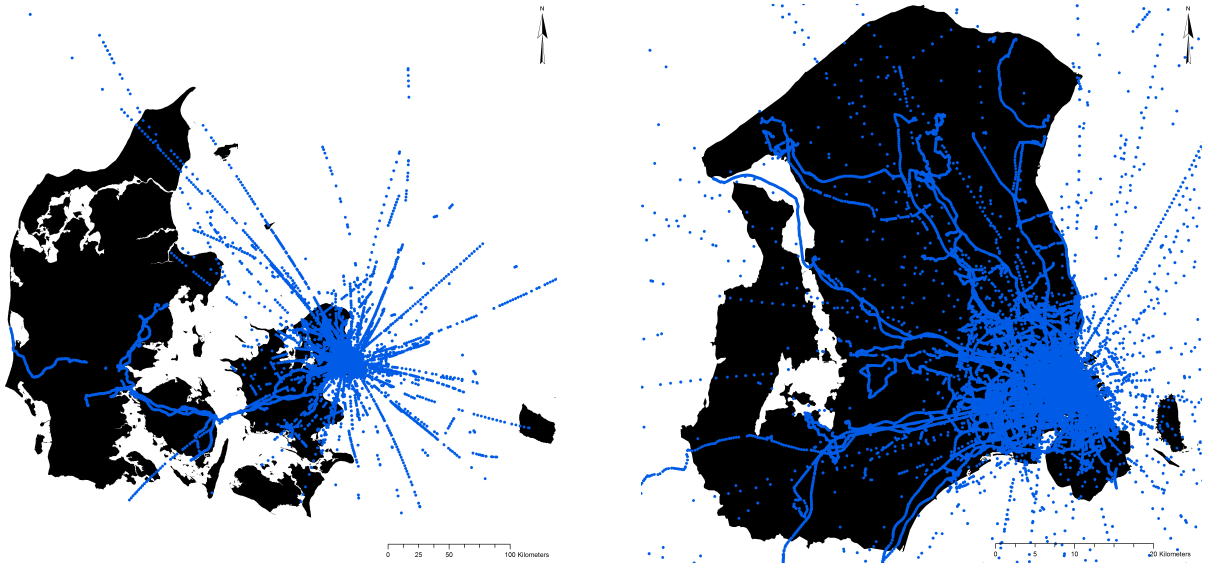


Figure 07

6.3 LINEAR PATH SCATTERING

This filter removes the earlier mentioned Linear Path Scattering error. When the phenomenon occurs, a series of loggings travelling a near-linear path which penetrates buildings, water and other topographic obstacles is recorded instead of the actual position of the GPS-receiver. Examples of this error can be seen in Figure 2 where very long series of linear path scattering radiate outwards from the case area. The error is occasionally detectable through either excessive speed values, or a low number of visible satellites. However, since this is not always the case, this filter is applied. The mechanism behind the filter is a scan for subsequent loggings with low difference in cardinal direction. Upon detection of such series, a polyline is constructed which is spatially compared with a network of roads and pathways. If the polyline resides within a reasonable distance of this network, the point series is evaluated, and if not, the point series is classified as linear path scattering. This filter classifies 50,607 loggings as erroneous. The effect can be seen in Figure 08.

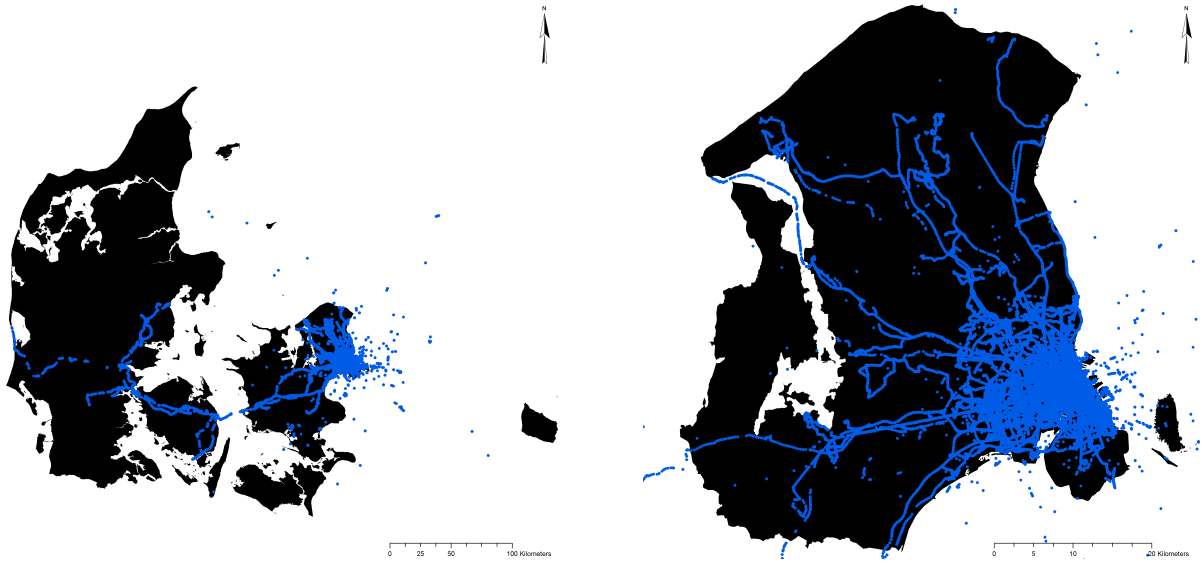


Figure 08

6.4 GEOGRAPHIC DELIMITATION OF THE CASE AREA

Since the purpose of the data gathering is to uncover patterns of transportation in Copenhagen using bicycles as the transportation mode, this filter removes all points which are deemed irrelevant based on their geographic location. As such, this filter removes all loggings residing outside the case area composed of the administrative border of the Capital Region of Denmark plus the closest neighboring municipalities in Region Zealand – Lejre, Roskilde, Solrød and Greve. As depicted by Figure 06, this filter is necessary since a proportion of the data is recorded outside of Copenhagen. This includes both obvious linear path scattering as well as loggings recorded during normal behavior on Funen and in Jutland. Both of these are considered irrelevant and are filtered based on a spatial comparison with a polygon covering the case area. This filter removes 103,254 loggings. A visualization of the effect can be seen in Figure 09.

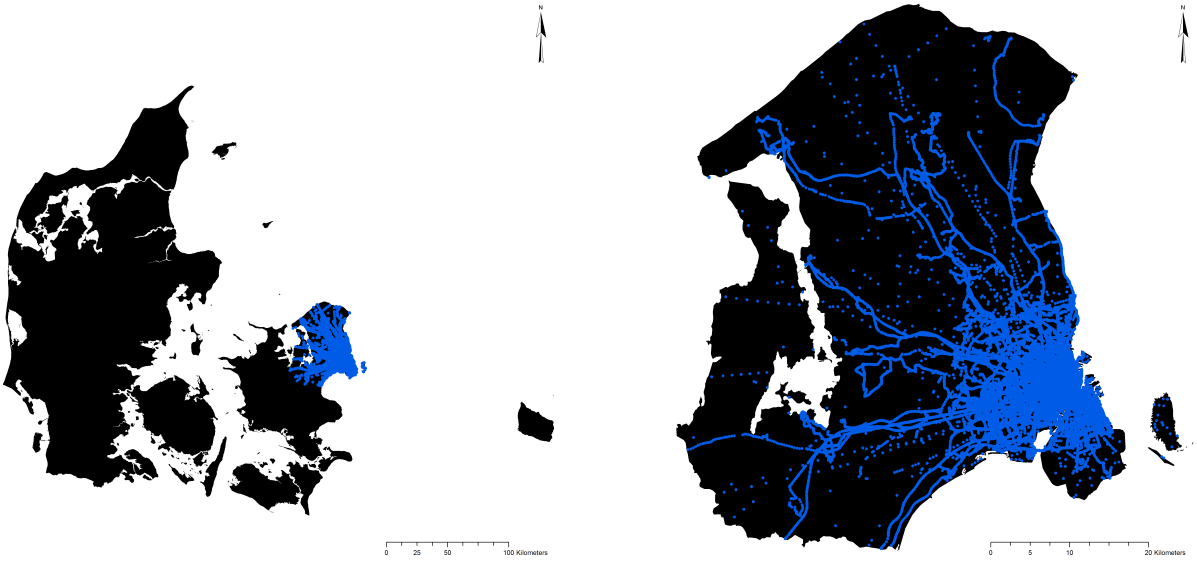


Figure 09

6.5 INSUFFICIENT AMOUNT OF VISIBLE SATELLITES

In order to yield a position through GPS, a minimum of three visible satellites is required to estimate planar coordinates. However, since this estimate is based on knowledge of the speed of light combined with a timestamp of the period at which the signal was emitted from the satellite and a timestamp of the time at which the signal was received, the estimate is very sensitive with regards to the accuracy of the clock in the receiver. As receivers generally have a relatively cheap quartz-clock to minimize the cost, as opposed to the much more precise atomic clocks which the satellites are equipped with, four visible satellites are preferred, as this allows for elimination of the error in the receiver clock. This does not mean that all loggings positioned with three visible satellites are erroneous, but they are generally considered too uncertain to keep. As such, this filter removes all loggings positioned with less than four visible satellites, which amounts to 346,502 loggings. The effect can be seen in Figure 10.

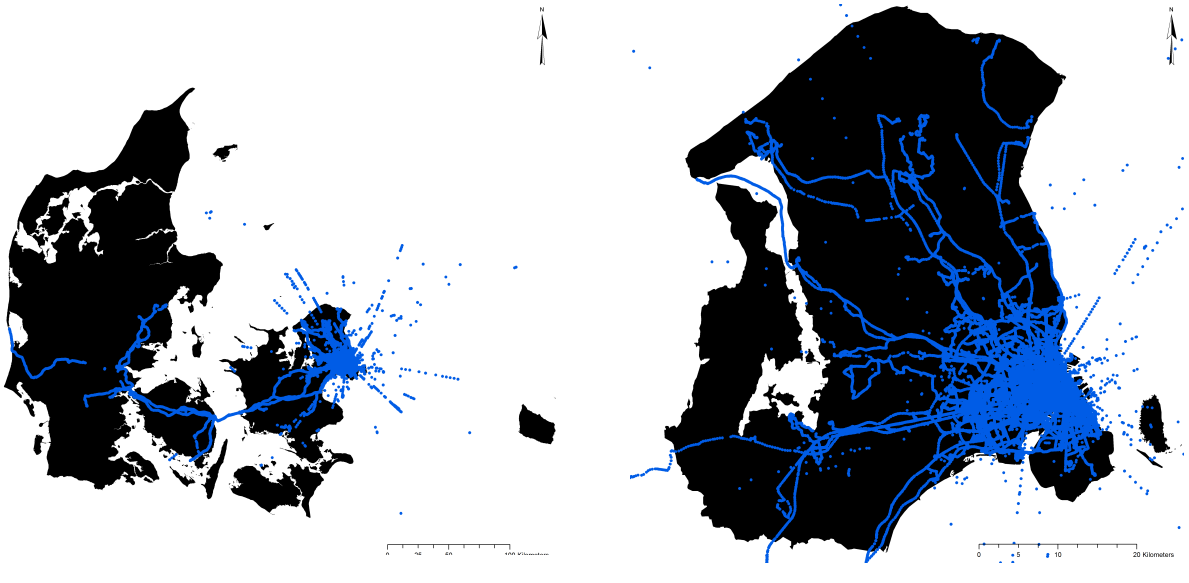


Figure 10

6.6. EXCESSIVE VELOCITY

Previous studies involving the same GPS-units show the receiver occasionally registers loggings where the co-ordinates are so faulty that it is reflected in the value of the speed-attribute. The reason for this is that the speed value is calculated based on the relation between time and space between two subsequent loggings. Since the survey revolves around bikes as the transportation mode, 50 km/h is considered a reasonable threshold. As such, this filter removes 55,164 loggings and the effect can be seen in Figure 11.

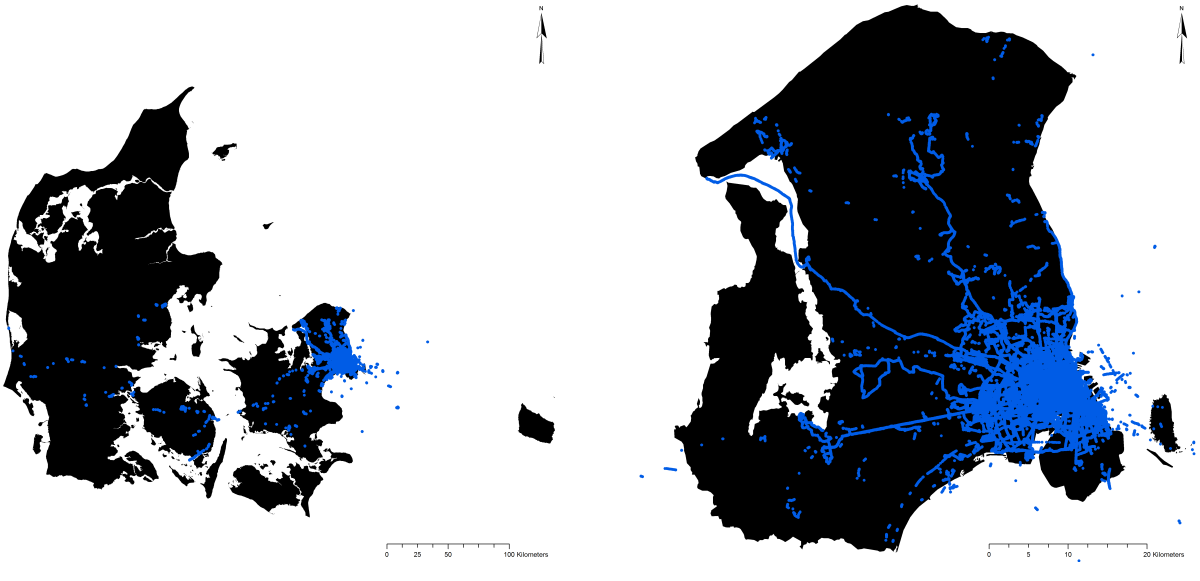


Figure 11

6.7 PARAMETER TIME TO FIX

The GPS receivers are configured to dismiss a position in case it is estimated with a satellite constellation deemed too poor. Satellite constellation with regards to positioning in the horizontal plane is measured by the value HDOP, which is an abbreviation of Horizontal Dilution of Precision. The default threshold for poor satellite constellation is 30. The parameter time to fix defines the amount of seconds the GPS-receiver had to wait until it could yield a satellite constellation better than 30 HDOP. In case the TTF value exceeds its threshold (60 seconds by default), the last good positioning is used instead. Any logging with TTF >= 60 is therefore potentially erroneous, as the coordinates belong to a previously recorded logging and depending on the difference in time, the GPS-receiver's actual position could have changed in the meantime. Thus, this filter removes 376,399 loggings. The effect can be seen in Figure 12.

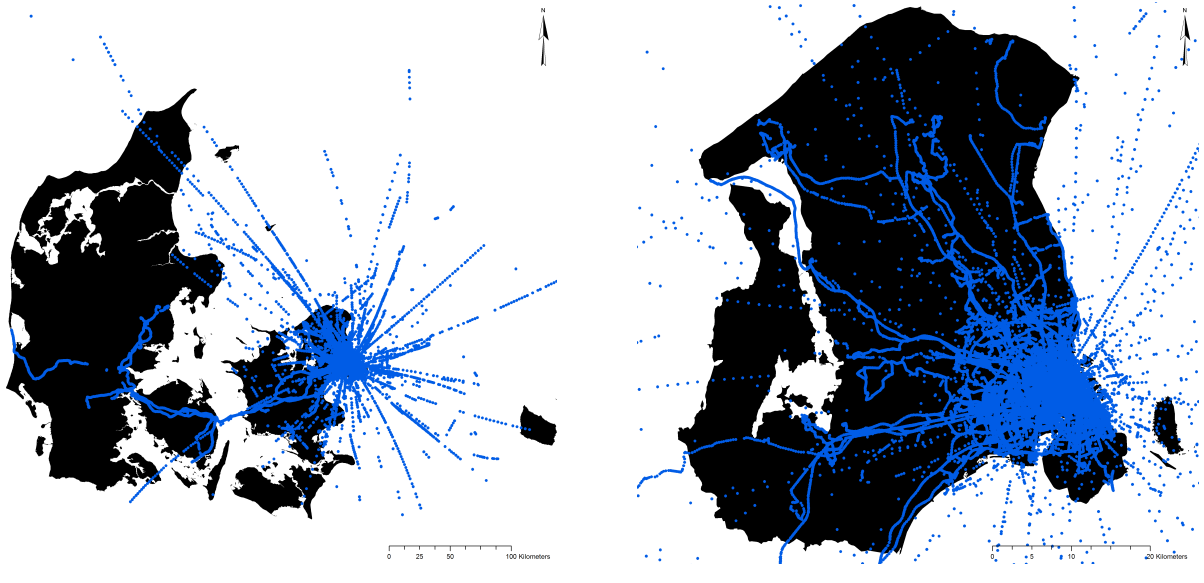


Figure 12

6.8 ALL ERRONEOUS LOGGINGS

This filter consists of a removal of all the loggings evaluated as erroneous or irrelevant through the previous filters. As such, the filter does not remove any loggings by itself – it merely accounts for the accumulated amount of errors. As previously mentioned, a single logging can be affected by multiple errors. Therefore, the accumulated amount of errors is less than the sum of all the errors detected by the previous filters. A total of 568,898 loggings are deemed as outliers of any kind. The combined effect of the filters is illustrated in Figure 13 whereas Figure 14 depicts the division into trips and stays after successful execution of the data cleansing.

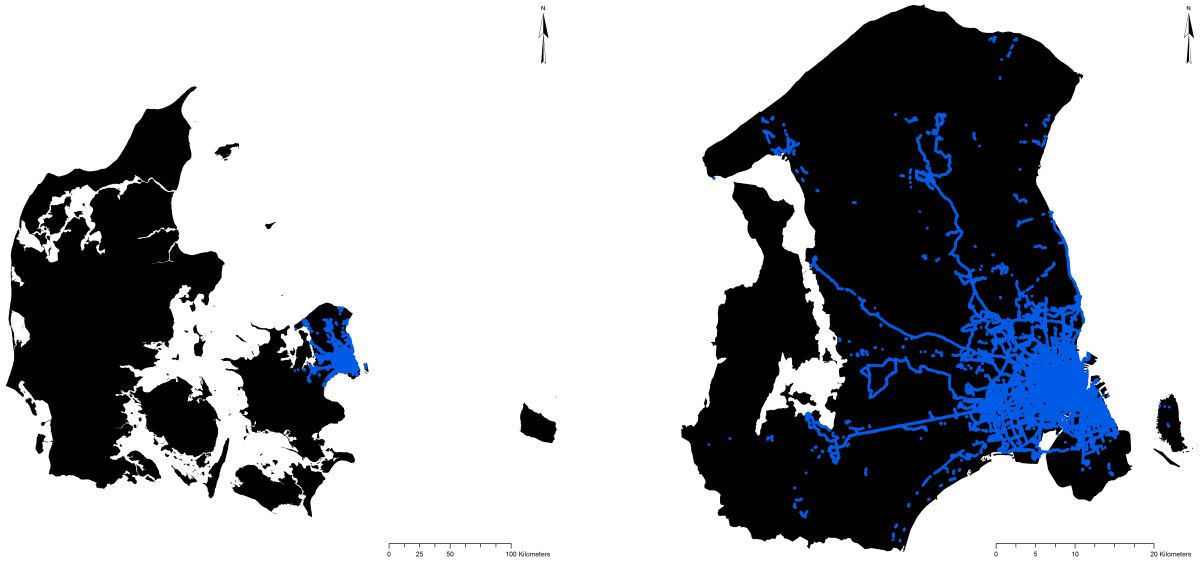


Figure 13

6.9: SUMMARY

An overview of the various filters' effect on the dataset can be seen in Table 03. As such, the final amount of valid loggings is 2,184,503.

Step	Loggings marked as errors	Trip-loggings marked as errors	Stay-loggings marked as errors
0	-	-	-
1	-	-	-
2	50,607	45,922	4,685
3	103,254	80,362	22,892
4	346,502	275,782	70,720
5	55,164	54,641	523
6	376,399	370,840	5,559
7	568,898	471,393	97,505

Table 03

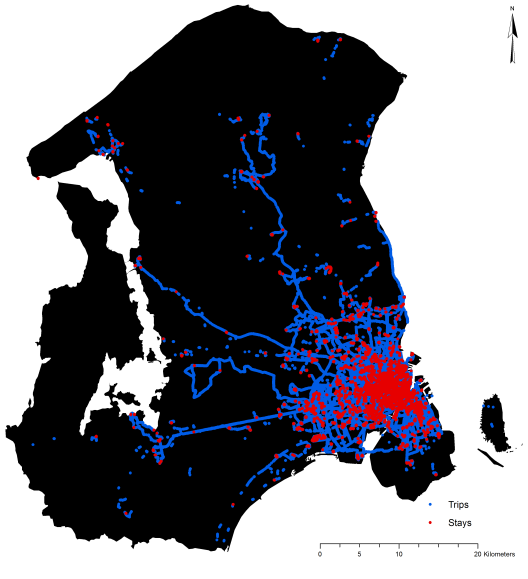
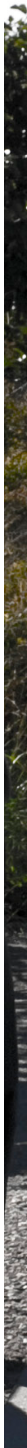


Figure 14

list of appendices




malbeck

APPENDIX A: 4 TEXT MESSAGES

Text 1

Kære XXXXX

Tak fordi du vil deltage i vores cykel undersøgelse, der starter i morgen. Din GPS skal sættes til opladning allerede i aften. Husk at medbringe din GPS hele ugen, ligegyldigt hvor du går hen. God fornøjelse med undersøgelsen!

Text 2

Kære XXXXX

I dag starter vores store cykel undersøgelse. Husk din GPS, når du forlader dit hjem i dag. Din GPS skal du have på dig hele tiden når du er ude og cykle. God fornøjelse med GPS'en!

Text 3

Kære XXXXX

Cykelundersøgelsen er nu afsluttet. Tak for din deltagelse. Husk at returnér GPS, oplader og rem til os, allerede i morgen.

Text 4

Kære XXXXX

Tak for din deltagelse i vores cykelundersøgelse. Vi er glade for, at du ville deltage. Husk at sende GPS, oplader og rem tilbage, så du deltager i lodtrækningen om en splinterny cykelhjelm til en værdi af 1000 kr., som også kan byttes til noget andet cykel udstyr. Portoen er betalt

APPENDIX B: RESPONDENT LOG

Respondkontakt uge 18.

Mandag 2.

Respondent aktivitet tjekkes

Mandag kl 8 - 10 6 responder kontaktes da GPS slukket - andre i live

#3	Arbejder hjemme men klar	kontaktet på mobil
#5	I udlandet - kommer først hjem fredag	kontaktet på mobil
#32	Brække hånd ude af undersøgelsen	kontaktet på mobil
#44	Vil ikke være med i undersøgelsen	kontaktet på mobil
#98	Arbejder hjemme	kontaktet på mobil

kl 15 - 17

#3
#5
#32
#44
#98

Tirsdag kl 8 - 10

#5	I udlandet - kommer først hjem fredag	
#32	Brække hånd ude af undersøgelsen	
#44	Vil ikke være med i undersøgelsen	
#99	Er tændt men ikke registreret på hjemmeside	kontaktet på mobil
#98	Arbejder hjemme	

kl 15 - 16

#99
#98

Onsdag kl 8 - 10

#5	I udlandet - kommer først hjem fredag	
#32	Brække hånd ude af undersøgelsen	
#44	Vil ikke være med i undersøgelsen	
#211	ikke hjemme før fredag	kontaktet på mobil

kl 15 - 16

#5
#32
#44
#211

Torsdag kl 8 - 10

#5	I udlandet - kommer først hjem fredag
#32	Brække hånd ude af undersøgelsen
#44	Vil ikke være med i undersøgelsen
#211	ikke hjemme før fredag
#220	GPS død

#42	ikke hjemme før søndag

kl 15 - 16

#5
#32
#44
#211
#220
#42

Fredag kl 8 - 10

#5	I udlandet - kommer først hjem fredag
#32	Brække hånd ude af undersøgelsen
#44	Vil ikke være med i undersøgelsen
#211	ikke hjemme før fredag
#220	GPS død
#42	ikke hjemme før søndag
#31	kontaktes da lommy er slukket

kl 15 - 16

#5
#32
#44
#211
#220
#42
#31

Lørdag kl 8 - 10

#5
#32
#44
#211
#220
#42

Respondkontakt uge 21.

Mandag 23 maj.

Respondent aktivitet tjekkes

Mandag kl 8 - 10 (6 "gule" respondenter)

#3	har ikke cyklet	kontaktet på mobil
#5	har ikke cyklet	kontaktet på mobil
#9	ikke hjemme	kontaktet på mobil
#23	ikke hjemme	kontaktet på mobil
#24	ingen kontakt	kontaktet på mobil
#27	har ikke cyklet	kontaktet på mobil
#29	GPS død	kontaktet på mobil
#97	ikke hjemme	kontaktet på mobil
#101	har ikke cyklet	kontaktet på mobil
#224	GPS død	kontaktet på mobil
#225	har ikke cyklet	kontaktet på mobil
#228	har ikke cyklet	kontaktet på mobil

kl 15 - 17

#9
#23
#24
#29
#97
#101
#225
#228

Tirsdag kl 8 - 10

#24	ingen kontakt
#29	GPS død
#101	har ikke cyklet

kl 16 - 18

#24
#29

Onsdag kl 8 - 10

#24	ingen kontakt
#28	har ikke cyklet
#29	GPS død

kl 15 - 16

#24
#28
#29

Torsdag kl 8 - 10

#24	ingen kontakt
#28	har ikke cyklet
#29	GPS død

kl 15 - 16

#24
#29

Fredag kl 8 - 10

#24	ingen kontakt
#29	GPS død
#221	GPS død

kl 15 - 16

#24
#29
#221

Lørdag kl 8 - 10

#24	ingen kontakt
#26	har ikke cyklet
#29	GPS død
#41	har ikke cyklet
#204	har ikke cyklet

kl 15 - 16

#24
#26
#29
#41
#204

Respondkontakt uge 21.

Mandag 23 maj.

Respondent aktivitet tjekkes

Mandag kl 8 - 10 Pinse!!!!! ps google maps virker stadigvæk ikke

#2	kontaktet pr. mail på grund af pinsen
#5	kontaktet pr. mail på grund af pinsen
#9	kontaktet pr. mail på grund af pinsen
#10	kontaktet pr. mail på grund af pinsen
#14	kontaktet pr. mail på grund af pinsen
#16	kontaktet pr. mail på grund af pinsen
#22	kontaktet pr. mail på grund af pinsen
#24	lommy ikke tilbage fra sidste runde
#25	kontaktet pr. mail på grund af pinsen
#26	kontaktet pr. mail på grund af pinsen
#30	kontaktet pr. mail på grund af pinsen
#31	kontaktet pr. mail på grund af pinsen
#36	kontaktet pr. mail på grund af pinsen
#37	kontaktet pr. mail på grund af pinsen
#43	kontaktet pr. mail på grund af pinsen
#46	kontaktet pr. mail på grund af pinsen
#51	kontaktet pr. mail på grund af pinsen
#53	kontaktet pr. mail på grund af pinsen
#98	kontaktet pr. mail på grund af pinsen
#99	kontaktet pr. mail på grund af pinsen
#100	kontaktet pr. mail på grund af pinsen
#213	kontaktet pr. mail på grund af pinsen
#215	kontaktet pr. mail på grund af pinsen
#220	kontaktet pr. mail på grund af pinsen
#225	kontaktet pr. mail på grund af pinsen
#226	kontaktet pr. mail på grund af pinsen
#227	kontaktet pr. mail på grund af pinsen

Tirsdag kl 8 - 10

#5	er med men har ikke brugt cykel	kontaktetet på mobil
#9	er med men har ikke brugt cykel	kontaktetet på mobil
#24	lommy forsvundet	kontaktetet på mobil
#25	GPS ikke kommet frem forkert adresse	kontaktetet på mobil
#26	Læser til eksamen - cykler ikke	kontaktetet på mobil
#37	er med men har ikke brugt cykel	kontaktetet på mobil
#39	er med men har ikke brugt cykel	kontaktetet på mobil
#46	er ude og rejse	kontaktetet på mobil
#99	er med men har ikke brugt cykel	kontaktetet på mobil
#220	intet svar	kontaktetet på mobil
#226	er med men har ikke brugt cykel	kontaktetet på mobil
#227	GPS ikke kommet frem forkert adresse	kontaktetet på mobil

	kl 15 - 16	#5	er med men har ikke brugt cykel
		#9	er med men har ikke brugt cykel
		#24	lommy forsvundet
		#25	GPS ikke kommet frem forkert adresse
		#26	Læser til eksamen - cykler ikke
		#37	er med men har ikke brugt cykel
		#39	er med men har ikke brugt cykel
		#46	er ude og rejse
		#99	er med men har ikke brugt cykel
		#220	intet svar
		#226	er med men har ikke brugt cykel
		#227	GPS ikke kommet frem forkert adresse
Onsdag	kl 8 - 10	#9	er med
		#24	ude af undersøgelse
		#25	ude af undersøgelse
		#26	ude af undersøgelse
		#37	er med
		#39	er med
		#46	er ude og rejse
		#99	er med
		#220	ude af undersøgelse
		#226	er med
		#227	ude af undersøgelse
	kl 15 - 16	#9	er med
		#24	ude af undersøgelse
		#25	ude af undersøgelse
		#26	ude af undersøgelse
		#37	er med
		#39	er med
		#46	er ude og rejse
		#99	er med
		#220	ude af undersøgelse
		#226	er med
		#227	ude af undersøgelse
Torsdag	kl 8 - 10	#9	har ikke cyklet
		#24	ude af undersøgelse
		#25	ude af undersøgelse
		#26	ude af undersøgelse
		#37	har ikke været hjemme
		#46	er ude og rejse
		#99	har ikke cyklet
		#220	ude af undersøgelse
		#227	ude af undersøgelse
	kl 15 - 16	#9	har ikke cyklet
		#24	ude af undersøgelse

		#25	ude af undersøgelse
		#26	ude af undersøgelse
		#37	har ikke været hjemme
		#46	er ude og rejse
		#99	har ikke været hjemme
		#220	ude af undersøgelse
		#227	ude af undersøgelse
Fredag	kl 8 - 10	#3	lommy død
		#5	har ikke været hjemme
		#13	har ikke cyklet
		#24	ude af undersøgelse
		#25	ude af undersøgelse
		#26	ude af undersøgelse
		#31	er med, men ikke cyklet
		#35	er med, men ikke cyklet
		#46	er ude og rejse
		#220	ude af undersøgelse
		#227	ude af undersøgelse
	kl 15 - 16		
		#3	lommy død
		#5	har ikke været hjemme
		#13	har ikke cyklet
		#24	ude af undersøgelse
		#25	ude af undersøgelse
		#26	ude af undersøgelse
		#31	har ikke cyklet
		#35	har ikke cyklet
		#46	er ude og rejse
		#220	ude af undersøgelse
		#227	ude af undersøgelse